where γ is the ratio of the two specific heats, p_0 the pressure, and ρ_0 the density of the standard gas at absolute temperature θ_0. S the specific gravity of the gas in question, and μ its viscosity. The conductivity is, like the viscosity, independent of the pressure and proportional to the absolute temperature. Its value for air is about 3500 times less than that of wrought iron, as determined by Principal Forbes. Specific gravity is ·0069.

For oxygen, nitrogen, and carbonic oxide, the theory gives the conductivity equal to that of air. Hydrogen according to the theory should have a conductivity seven times that of air, and carbonic acid about $\frac{7}{9}$ of air.

III. "On the means of increasing the Quantity of Electricity given by Induction-Machines." By the Rev. T. Romney Robinson, D.D. Received May 10, 1866.

Among the remarkable results obtained by studying the spectra of electric discharges, is the change exhibited by certain substances when the nature of the discharge is varied. In general the mere spark shows fewer and fainter lines than when a Leyden jar is in connexion, though the amount of electricity supplied by the machine is the same. In the latter case, however, the discharge passes almost instantaneously, and therefore its concentrated action will be more powerful. But, as far as I know, much has not been attempted towards increasing the power of the jar: this cannot be done by increasing its surface (unless indeed that be too small to condense all the electricity supplied); the supply itself must be increased.

This may be done in three ways:—

First, the power of the exciting battery may be increased. This, however, is limited by the risk of destroying the acting surfaces of the rheotome; and by the decreasing rate at which the magnetism of the iron core increases with the primary current. In some investigations on the electromagnet (Trans. Irish Academy, vol. xxiii. p. 529) I have shown that its lifting power L is approximately given by the equation

$$L=\frac{A\Psi}{B+\Psi},$$

in which Ψ is the product of the current and number of spires, A the maximum lift of the magnet, and B the Ψ which would excite it to half A. The rate of change $\frac{dL}{d\Psi}$ is therefore inversely as $(B+\Psi)^2$. The results obtained with two of the magnets which I used will illustrate this. Their A's are 781 lbs. and 278. The first 1000 of Ψ make their lifts 576 and 235; the second 1000 adds to these 87 and 19; the third 35 and 8; and the fourth only 19 and 3. With a primary of 180 spires, $\Psi=4000$ implies a current which can evolve in a voltameter 34·7 cubic inches of gases per minute, and of course has great deflagrating power. There is therefore not much to be gained in this direction.

Secondly, the secondary helix may be made of longer or thicker wire. It will be shown immediately that the length does not increase the quantity of the current at all, and that the effect of the thickness is limited.

Thirdly, the analogy of the voltaic battery suggests the plan of combining several helices collaterally, as is done when cells are arranged for quantity; and this I think may avail to a very great extent.

In spectral work, as in most other applications of the inductorium (as the Germans have named it), the breaking current alone is of importance: the other, though equal in quantity, is so much inferior in tension that it is stopped by a thin film of highly rarefied air*. This current proceeds from two causes. When the circuit is broken, the current in the primary ceases; not instantaneously†, but in a time which is very small; according to Edlund less than $\frac{1}{200}$ of a second. During its decline it induces a current in the secondary. But while it was passing it had magnetized the iron core of the apparatus: this magnetism now passes away, and in doing so it also induces a current in the secondary, which lasts longer and is more powerful than the other. I compared the two by measuring those given when the core was removed from a primary, and when it was in its place: they were as $1:8{\cdot}62$ when the rheotome made 17 discharges in a second; so that in round numbers the electric induction was only a tenth of the whole effect. I shall therefore in what follows confine myself to the magnetic induction.

If y be the magnetism at any time t, M its maximum, P the potential of the magnet on the secondary helix, Π the potential of that helix on itself, r the resistance of the secondary circuit, ϕ the secondary current at the time t, we have, as is well known,

$$\phi=\frac{\mathrm{P}}{r}\times-\frac{dy}{dt}-\frac{\Pi}{r}\times\frac{d\phi}{dt}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

the last term being the counter current produced by the reaction of ϕ on the helix. If the inductive coefficient of electric action be different from that of magnetic, Π should be multiplied by a factor e, which in (b) will multiply μ in the exponent and denominator. I see no reason why they should differ unless some work be lost by molecular changes in the core when excited. The great difference between the two currents which I have just mentioned arises most probably from the different values of t in the exponentials.

To integrate (a) we must assume some relation between dy and dt. The

* This is not quite correct. Mr. Gassiot showed from the reversed curvature of the strata in an exhausted tube that some of the closing current does pass when the action is powerful. The same conclusion follows from a fact which I observed last year with Mr. Atkinson's magnificent Ruhmkorff. In general when a discharge is made between platinum points, the negative one only is ignited; in this case the positive one was so also, though to a far less degree and for half the length.

† As the tension at the opening of the rheotome decreases, so must also the velocity of discharge there; and time is required for the passage of the electricity from the centre of the circuit to its extremities.

most probable is that the loss of magnetism is as the magnetism, which gives $\frac{dy}{y} = -\mu dt$, whence $y = \mathrm{M}e^{-\mu t}$.

Putting $b = \frac{r}{\Pi}$, and supposing ϕ to vanish with t,

$$\phi = \frac{\mathrm{P}}{r}\mathrm{M} \times \frac{\mu b}{\mu - b}\left\{\left(\frac{y}{\mathrm{M}}\right)^{\frac{b}{\mu}} - \frac{y}{\mathrm{M}}\right\}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

The total current in the time $t = \Phi = \int_0^t \phi dt = \int -\frac{\mathrm{P}}{r} dy - \frac{1}{b}\int d\phi$, and hence putting F for $-\frac{\mathrm{P}}{r}(\mathrm{M} - y)$ and c for $\frac{y}{\mathrm{M}}$, we obtain

$$\Phi = \frac{\mathrm{F}}{1-c}\left\{1 + \frac{bc}{\mu - b} - \frac{\mu c^{\frac{b}{\mu}}}{\mu - b}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

The expression for the current due to the electric induction will be similar to this, so far as having the factor F and the exponential. If, as is not unlikely, the relation of $d\mathrm{E}$ to dt be the same as for the magnetism, they would only differ in the values of μ and c.

The quantity F is the current which would be produced were it not for the inductive reaction of the current on itself. It is as P directly and r inversely. The first of these, P, is as n the number of spires in the helix* multiplied by a rather complex function of its length and diameter, which is constant when they are given. The second, r, may be assumed proportional to the length and section of the wire of the helix, for in general the other resistances of the circuit are comparatively small. Hence it follows that

If two equipotential helices equally excited be placed in series, the tension will be doubled; but the current will be intermediate between that of each, for $\mathrm{F} = \frac{2\mathrm{P}}{r + r'}$, and if $r = r'$ it will not be changed. If they be used collaterally (their homonymous terminals connected), P remains unchanged, and therefore the currents of the helices are simply added. If there be an external resistance, allowance must be made for it. This may be extended to any number of helices; for calling the external resistance ρ, we find

$$\mathrm{F}_n = \frac{\frac{\mathrm{P}}{r} + \frac{\mathrm{P}'}{r'} + \ldots \frac{\mathrm{P}_n}{r_n}}{1 + \rho\left(\frac{1}{r} + \frac{1}{r'} \ldots + \frac{1}{r_n}\right)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

The constant c must be a small fraction, for in any ordinary work of the inductorium the residual magnetism of the core is very feeble. As $it = e^{-\mu t}$, μt must be large; and as t for wire cores does not exceed a few hundredths of a second†, μ must be very large.

* Not as the mere length of wire, as is sometimes loosely stated.

† I have been informed that with the inductorium which Mr. Whitehouse constructed for the first Atlantic telegraph, the cores of which were massive iron cylinders, the discharge lasted some seconds. If it be still in existence, it would be interesting to examine the spectra which it would give.

The potential Π is as n^2 multiplied by another function of the length and diameters of the helix (see Maxwell's valuable paper "On the Electromagnetic Field," Phil. Trans. 1865); and the term b is always less than unity. When helices are consecutive their Π's are added, not when collateral.

From this it follows that $\frac{bc}{\mu-b}$ may be neglected; that $\frac{\mu}{\mu-b}$ is nearly unity; and that the difference between F and Φ increases as b diminishes.

When equal helices are consecutive, b as well as F are unchanged; therefore so is Φ.

When they are collateral, each separate b remains unchanged (unless they be so close that they react on each other); and therefore, as with F, the resultant Φ is the sum of its components.

If the resistance of the wire be diminished by increasing its section without making much change in the dimensions of the helix, b is diminished, and therefore the coefficient of F. It is evident from the form of equation (c) that Φ has a maximum for r, and that beyond this there is actual loss of power in increasing the thickness of the wire.

It remained to test these views by experiment, but the task has some difficulties. A single discharge of inductive electricity is usually determined by the swing which it causes in a galvanometer needle; but it is scarcely possible to get two discharges exactly equal. The slightest variation in the manner of breaking the circuit, the least oxidation or roughening of the surfaces where the break is made, change the result; and therefore it seemed best to take the actual working of the inductorium, in hopes that the average of some thousand discharges must be near the real value of the current.

The rheometer which I used is Weber's (for the use of which I am indebted to the kindness of Mr. Gassiot), and it showed an amount of fluctuation even greater than I expected. With every precaution as to the action of the rheotome, the mirror of the Weber never becomes stationary, and the oscillations are irregular; twelve of them were taken for each set, of course read at each end and reduced by the usual formula; yet the sets differ so much, that I only offer their results as tolerable approximations. Two facts illustrating this uncertainty may be mentioned. With a mechanical rheotome driven at a uniform speed, and its acting surfaces platinum, the ratios of the current were—

When set so that the point rises but little from the anvil ..	1·0000
Rise greater	1·7894
Rise still greater, tension of spring greater	1·9685
Rise still greater, tension further increased	1·8371

Here a slight change of the adjustment nearly doubles the action of the inductorium.

Another cause of uncertainty is the variable speed of the rheotome. In general it is worked by the primary current, and therefore is affected by fluctuation of the battery and the extra current of the primary. The me-

chanical rheotome which I have mentioned is driven by clockwork, and its speed can be exactly regulated. With it I obtained

1.	Time of rheotome's stroke	= $0^{s}\cdot2865$.	Current	= 1·0000
2.	,, ,,	0·2020.	,,	0·9298
3.	,, ,,	0·1862.	,,	0·8741
4.	,, ,,	0·1381.	,,	0·7235
5.	,, ,,	0·1219.	,,	0·5771
6.	,, ,,	0·1201.	,,	0·5588
7.	,, ,,	0·0983.	,,	0·3788
8.	,, ,,	0·0883.	,,	0·2823
9.	,, ,,	0·0671.	,,	0·2478
10.	,, ,,	0·0476.	,,	0·2007
11.	,, ,,	0·0278.	,,	0·1946
12.	,, ,,	0·0196.	,,	0·1273
13.	,, ,,	0·0098.	,,	0·0470

No. 10 was taken with a mercurial rheotome; and the remaining three with a spring one, such as Mr. Ladd applies to his inductoria*.

This decrease of power is due to the core requiring time to be magnetized. Suppose the current $=A+Bt$, A being that caused by the electric induction, B by the magnetic, I get from the above by minimum squares $A=0\cdot0802$; $B=4\cdot1713$; $\frac{B}{A}=508$; which values represent the observations pretty fairly, the probable error being $\pm 0\cdot0491$. Three cells were used here: on another trial with five I had $\frac{B}{A}=129$, confirming a previous remark that the electric induction increases faster than the magnetic. Hence much power is lost by working at too high a speed.

The inductorium which I use consists of a strong oak table, on which are fixed vertically four primary helices, their axes being 12 and 18 inches apart; at which distance the mutual action of the secondary helices is scarcely sensible in the Weber. I denote these primaries by P', P'', &c. Their wire is No. 12; P' and P'' are 12·5 inches long; they have, in four layers, the first 383 spires, the second 343†. Their cores of iron wire, No. 18, are 1·12 diameter. P''' and P^{iv} are 13·5 inches long; they have each 181 spires in two layers, and their cores are 1·60 diameter. They are all insulated by strong glass jars, and their connectors are so arranged that the current can be sent through any one separately, or through all at once. The normal arrangement is that the battery-current passes through P''', then through P' and P'' collateral, and lastly through P^{iv}. Thus the Ψ or exciting power of each primary is nearly the same. On a shelf below stands a Fizeau's condenser, each of whose coatings is 120 feet divided into

* For the first nine of these the time was given by the clockwork of the rheotome; for the rest by dropping sparks on a slip of prepared paper, which was made to travel at the rate of 12 inches per second.

† The difference arose from the cotton lapping being thicker in P''.

five sections. This, though so potent in respect of sparks, does not affect the quantity, which with it I found as 1·0000, without it 0·9948, a difference not worth noting. The case, however, would be different if there were a gaseous interval in the circuit*. Beside this shelf is a bracket which supports rheotomes of various kinds.

Over the jars can be put any of the secondary helices, the constants of which are given in the following Table:—

The potential P and resistance of the first one, which I take as a standard, are assumed =1.

TABLE I.

Name.	Feet of wire.	Diameter of wire.	Layer.	Spires.	Entire diameter.	Height.	Potential. P.	Resistance. r.
		in.			in.	in.		
G	17,070	0·0092	73	13,655	6·84	4·0	1·00000	1·00000
H	17,070	0·0092	73	13,655	6·84	4·0	1·00000	0·85270
I	8,110	0·0153	55	6,570	6·72	4·0	0·48114	0·10079
K.........	8,110	0·0153	55	6,570	6·72	4·0	0·48114	0·10079
M	8,130	0·0192	29	6,524	6·21	6·0	0·47520	0·08073
N.........	8,130	0·0192	29	6,524	6·56	5·9	0·47520	0·08282
A.........	7,000	0·0107	...	6,189	5·93	3·5	0·44673	} 0·51808
B.........	9,200	0·0107	...	8,135	5·93	4·0	0·60272	

The first six were made by Mr. Ladd, who also determined for me the length and number of layers. The thickness of the wires was measured by me with a fühlhebel which read to 0·0001: each is a mean of ten measures at different places, for no wire that I have ever tried is quite uniform. The two last are experimental, their wire not being lapped, but merely insulated by a varnish of wax and rosin, as proposed by the late Dr. Callan: this plan does well for quantity, but cannot be trusted for any high tension.

The potentials were computed, supposing the helices at the middle of tke primary P''' (where they are a maximum). For G I computed them in four other positions, and had the curiosity also to measure the currents.

Distance of G from centre	=0,	potential 1·0000,	current	1·0000
,, ,,	1,	,, 0·9842,	,,	0·9856
,, ,,	2,	,, 0·9790,	,,	0·9746
,, ,,	3,	,, 0·9488,	,,	0·9488
,, ,,	4,	,, 0·8798,	,,	0·9181

All but the last agree tolerably. For positions of M and N, which were not central, they were specially computed.

The resistances were obtained by including in the circuit of a small Grove's

* Three of the combinations described in Table II. have tensions nearly as 1, 2, and 3. Their quantities, with a circuit entirely metallic, and with one in which there was an interval of $\frac{1}{8}$ inch of air at 0·01 in. pressure, are as

G	entire 1·0000,	interval 1·0000
G+H...............	,, 1·0348,	,, 1·5580
V+V'	,, 0·9994,	,, 1·8844

The first set are nearly equal; the second increase, though at a decreasing rate, with the tension.

cell and a tangent rheometer of 950 spires, first the helix G, then that to be determined, and lastly the sum of it and G. Assuming G=1, we have three equations to determine—the r of the helix in question, the remaining r of the circuit, and the electromotive force of the cell. In deducing the currents, the term involving $\sin^2\theta$ was used with a coefficient obtained by integrating through the length and breadth of the rheometer's coil; and as its mean diameter is 6·4 times the length of its needle, and θ never passed 54°, I think the numbers of the Table are true to the last decimal.

For brevity I symbolize the combinations, when in series, as a sum, G+H; when collateral, as a product G.H; and for a reason which will soon appear, when two are on the same primary I denote them by a new letter, as V=G+I. At first I used I and G on P‴; K and H on P^{iv}. To prevent disruptive discharge, they were kept 1·5 inch asunder by disks of baked wood. The results are given in

Table II.

Name.	Φ.	F.*	Spark.	Sets.	$\frac{\Phi}{F}$.	Sum of components.	Π.	b.
			in.					
G	1·0000	1·0000	3·95	...	1·00000	......	1·00000	1·00779
H	...	1·1000	3·37	...	...	......	1·00000	0·985385
G+H	1·0348	1·0096+	...	3	1·02497	......	2·00000	0·92306
G.H	1·9988	2·0223	...	4	0·98837	2·0855	1·00000	
I	2·5343	4·3635	1·23	1	0·59167	......	0·23149	0·46542
I+K	2·7654	4·5358	2·49	3	0·60969	......	0·46298	0·44872
G.H (I+K)	3·0552	6·5756	0·80	4	0·46462	4·6220		
V+V′	0·9996	1·3776	9·35	3	0·72562	......	2·46298	0·83075
V.V′	1·9434	2·7319	4·39	1	0·71138			

F is computed with a correction for the place of the helix on the primary, and with a resistance which includes that of the Weber =0·00779. The Weber must have a considerable Π of its own; but as I did not know its constants, and as this Π must vary with the deflection, I did not compute it. Possibly some of the discrepancies may be owing to this. The sparks show the difference of tension; they were taken with platinum points, and when the machine was excited by four Groves. The column, sum of components, gives for the collateral combinations the values which arise from adding the Φ of each helix, taking into account the Weber's resistance.

1. It will be observed that G+H with twice as many spires, and V+V′ with thrice as many as G, give the same current; so also that of I+K is near that of I.

2. On the other hand, G.H is twice G, and V.V′ twice V+V′.

3. It is also manifest that the effect of I is not proportional to its diminished resistance: its F is 4·4 times greater than that of G, but its actual

* These values of F should be multiplied by a factor representing the F of G, which must be greater than its Φ, here assumed as unity. As, however, it belongs to all, its omission does not affect the comparison.

current is only 2·5. This is at once explained by its b being so much less. So also the ratio of the theoretic to the effective current is nearly unity in G+H, while it is only 0·73 in V+V′, and for the same reason. In G.H.(I+K) the ratio is still smaller; but I shall recur to this.

I now used the four primaries I+K=L on P^{iv}, single helices on the others. I had some doubt whether the difference of the cores might not influence the results, and tried this with P′, P‴, and one P^{v}, whose core =1·90 inch in diameter and 15·5 inches long. It has 349 spires of No. 15 in two layers. G was put on each of them, and currents transmitted, which made their Ψ's nearly equal.

TABLE III.

Name.	Sect. of core as	Φ.	Sets.	Spark.	Ψ.
P″	1·00	1·0414*	3·5	2·225	1169
P^{iv}	2·04	1·0000	2·	3·237	1168
P^{v}	3·00	1·0054	2·	2·662	1156

It follows from this that the least of these cores is large enough for the excitation produced by four cells: the size does seem to increase the spark, though this increase may be owing to better insulation of the core-wires in P‴ and P^{v}†.

The following results were obtained with the mechanical rheotome worked at a uniform speed of 13 discharges per second.

TABLE IV.

	Φ.	F.	Sets.	$\frac{\Phi}{F}$.	Sum of components.	Π.	b.
G..............	1·0000	1·0000	...	1·00000	......	1·00000	1·00779
L=I+K ...	1·8832	4·5106	19	0·41752	......	0·6+	0·34624−
G+L	1·3149	1·6143	2	0·81451	......	1·6+	0·75002−
G.L	3·0402	5·3109	11	0·57159	2·8324		
H	1·4196	1·3578	2	1·04551	......	1·00000	0·85385
C=A+B ...	1·9882	2·0112	2	0·99855	......	0·56286+	0·92704
N..............	2·5535	5·4100	1	0·47202	......	0·31646	0·27756
I	2·5580	4·3635	2	0·58623	......	0·23149	0·46542
K..............	2·6465	4·3635	5	0·60651	......	0·23149	0·46542
G.K	3·5558	5·2464	1	0·67776	3·8594		
G.L.H......	4·3179	6·5756	3	0·65666	4·1799		
G.L.C	5·1460	6·9400	3	0·74153	4·6932		
G.L.C.H...	6·0758	8·2081	3	0·74030	6·0488		
M+N.........	2·5207	5·4586	2	0·46179	......	0·63292	0·26862
=O...........	1·7616	5·4586	4	0·32271	......	0·73130	0·23248
S=M+N ...	1·6687	4·9644	1	0·33614	......	0·65810	0·28543
L.O	3·4596	9·5774	1	0·36124	3·4996		
M N I K ...	8·1939	15·7398	1	0·52058	8·2736		

* 2·5 sets taken on the first day were very unsteady. The one taken on the second was close, and gave 1·0267.

† At the same time I tried two helices similar to A and B, except that their wire is varnished *iron*, which were given to me by Dr. Callan. Their Φ is 0·6887, and their spark only 0·524 in. The Φ of A+B is 2·9138 times as great, a difference caused solely by the greater resistance of the iron.

1. As before, two helices in series give no increase of quantity; M+N is the same as N, G+L nearly the mean of G and L.

2. The quantity of collateral helices is seen in column 6 (as in Table II.) to be the sum of the separate actions of each. The discrepancies are not greater than what can be explained by the uncertainties inherent in these measures, which I have already described. One apparent exception is a strong confirmation of this rule—the case of G . H (I+K). Its observed $\Phi=3\cdot0552$, while the sum $=4\cdot6220$. G and I being on the same primary are excited together; but in measuring either, as there is no current in the other (but merely a state of tension), their Π is not changed. When, however, they are connected collaterally, the currents react on each other, their Π's are increased: the Φ's are thus diminished, and therefore their resultant is the sum of quantities less than those used in the computation. The b's in this case become—for G $0\cdot94289$, for H $0\cdot79885$, and for I+K $0\cdot34588$, which are quite sufficient to account for the difference.

3. As with I in Table II., so here it will be observed that N has less relative power than either I or K; its actual power is even less, though its theoretical force exceeds theirs in the proportion of 5 : 4. This is explained by its b being so much smaller; but it gives this important information, that, at least in helices of these dimensions, nothing is gained by using wire thicker than that of I, or $\frac{1}{65}$ of an inch*.

4. The effect of L is far less than that of I+K. In the first the helices are on the same primary, in the other on separate ones. In the former case the Π is larger, for it is the sum of the Π of each on itself, and those of each on the other; b therefore is less. Besides, the potential of the core on the helices is less than when each of them is central on it.

The difference is even more remarkable in O as compared to its elements M+N, its effect being only $0\cdot7$ of the other, and $0\cdot3$ of the theoretic power. The same disparity of course prevails in their combinations; O . L giving only $3\cdot46$, while the same four helices arranged on separate primaries give $8\cdot19$. The combinations G . H (I+K) and G . L . H have the same helices; but in the first two were on the same primaries. As, however, they were $1\cdot5$ inch instead of $0\cdot5$ apart, the Π was not so much increased as in the other cases, and therefore there is not quite so great a decrease of power.

The following practical maxims may be deduced from the experiments and reasoning which I have related.

The attention of instrument-makers has been chiefly directed towards increasing the length of spark given by these machines, and in this they have succeeded to a surprising degree; but in doing so they have not added to the quantity of electricity which is produced by them. This, however, is by far the most important object; for in most applications of

* This is between 27 and 28 of the Birmingham wire-gauge. I believe Ruhmkorff uses 28.

the inductorium all tension above what is necessary to force the necessary quantity of current through the circuit is useless, nay sometimes injurious*. I am inclined to think that a tension which gives sparks of 4 inches will be found quite sufficient in ordinary cases, and this will be given by about 20,000 spires; all beyond only adding to the weight of the instrument, its cost, and the difficulty of insuring its insulation. It must be kept in mind that the mere quantity is independent of the length of wire: I actually found it the same for a flat spiral of 21 spires and for a helix of 13,655.

It is not, I believe, ascertained what is the best proportion of height and diameter for a secondary helix of a given number of spires. It is generally made as long as its primary, though perhaps not on any definite principle. The magnetic potential P is in this form a little greater than in that which I used, but so also is Π: the length of wire is less, which increases F, but also decreases b; and *à priori* it is not easy to decide which way the balance inclines. The Π is something less if the spires be in separate sections than if they be in one continuous coil.

The dimensions of the core do not seem to be of importance as to quantity within the limits which I tried; their length seems to increase the tension.

The quantity is greatly diminished when the rheotome works rapidly; and in spectral work the probable limit of its slowness is that the impression on the eye shall be continuous.

The quantity increases with the diameter of the wire up to a maximum, which is attained when this is about the sixty-fifth of an inch.

Helices may be combined either for tension or quantity without much loss of these respective powers†.

If for the first, they are combined in series; the general tension is the sum of the individual ones, and in this way we can obtain sparks of a length limited only by the strength of the insulator which is interposed between the primary and secondary helices. If the latter be all of the same wire, the quantity remains unchanged; if they differ in this respect, it will be intermediate between the weakest and strongest.

If they are combined for quantity, they must be set collaterally, *i. e.* all their positive terminals connected, and all their negative. The resulting current will be the sum of all the separate ones, but the tension is not increased; the sparks seem even a few hundredths of an inch shorter, but are much denser, and in the higher combinations approach to the character of a jar discharge. Hence there is no risk to the apparatus by extending this mode of combination to any extent.

It deserves notice that the helices need not be equal in tension or resistance; thus the arrangement G . K gives little less than the sum of its

* It has often been remarked that intense discharges will not show strata well in an exhausted tube.

† The connectors add some resistance and some counter-induction.

components, though K has only half as many spires as G and but a tenth of its resistance.

In combining these instruments, the primaries should not be consecutive if of large numbers, for so the action of their extra-current would be very destructive to the rheotome; with $P'+P''$ containing 726 spires in series the spark in the mercurial one is almost explosive, but when they are collateral it works quietly. Were, however, ten or twelve to be so combined, it would require a battery of very large cells to maintain the current, and it is better to have a separate battery for each pair of primaries. In this I find no difficulty; the negative* poles of all the batteries are connected with the mercury of the rheotome; from its platinum point, separate wires go to the entering bind-screw of each primary, other wires go from their exit bind-screws to the positive poles of their respective batteries, and thus their action is perfectly simultaneous. Of course, if many batteries were used, the current in the rheotome might be too powerful, but then there would be no difficulty in having separate rheotomes worked by one electromagnet, and (at least with the mercurial form) adjusting them by a revolving mirror to perfect synchronism.

In this way I feel sure that we can attain an amount of electric power which has not yet been approached by the inductorium, and which may be expected to be a most powerful means of research in those inquiries to which I referred at the commencement of this paper. At the head of these stands the palmary discovery of Mr. Huggins, that there are nebulæ and comets whose matter possesses spectral attributes not corresponding to that of the sun, the stars, or our own earthly elements. Is that difference an indication of some body *sui generis*, or a mere result of peculiar temperature or other molecular conditions? Is, for instance, the bright line, corresponding to one of nitrogen, which occurs, we may say, normally, produced by nitrogen as such? If so, what has blotted out the other bright lines of that magnificent spectrum? Is it due to an *element* of nitrogen, dissociated by some enormous temperature from other elements, perhaps from hydrogen, one line of which is also present? And the third line, elsewhere unknown—is it the herald of a new body, or merely a derivative from another spectrum? We cannot even hope for an answer to these questions till the spectra of at least those elements which seem cosmical have been examined through a range of temperature extending from the lowest that developes in them luminous lines, to the highest that is excited by the most potent electric discharges which we can produce and control. Now, to obtain such a graduated range, the plan of combination which I have been describing seems well fitted. It, of course, cannot be expected to equal, under any extension, the wonderful voltaic battery of Mr. Gassiot (at least its arc-discharge); but how few can avail themselves

* If the mercury be made positive, each discharge makes a sharp report and blows about the metal and alcohol in most unpleasant profusion.

of such an instrument as that! But if, as seems probable, we can without much difficulty increase the heating-power of the induction-discharge an hundredfold, we shall have made a very great step, and by means which are everywhere accessible. Inductoria are common; there are few situations where a physicist cannot obtain access to several, and combine them as Despretz did the voltaic batteries of Paris to make the experiments which have thrown such splendour on his name.

IV. "On the Stability of Domes." By E. Wyndham Tarn, M.A. Communicated by George Godwin, Esq. Received May 5, 1866.

The few writers who have attempted to treat the subject of the Equilibrium of Domes mathematically, have entirely failed to obtain results that are of any practical use to the architect. Their failure has arisen from taking a too theoretical view of the subject, and endeavouring by mathematical reasoning to find the *form* which a dome ought to have in order that it might stand safely. Such a question is of no practical utility, as domes of various sizes and forms have been erected for centuries past, and the question for the architect is,—given a dome of certain form and size, what are the conditions which must obtain between it and the wall of the building it is intended to cover, in order that the whole structure may be in a condition of stability?

The object, therefore, of this paper is to find a solution to the following problem:—

Given a spherical dome, built of stone or brick, of any radius and thickness, and standing on a "drum" or walls of any height; to find the thrust of the dome on the "drum," and the thickness that must be given to the walls in order to insure the stability of the structure.

I take the case of the dome having a spherical section, as being the form most commonly used; but the same method of investigation will apply to domes of any form.

In this investigation I shall consider the dome as made up of a large number of arched ribs, of which the bases resting on the top of the "drum" subtend a small angle (ϕ) at the centre, and the vertices have no thickness; each rib having the form of a wedge cut out of the spherical shell by two planes intersecting in a vertical line through the centre, and making the small angle ϕ with each other. I shall then consider that the two wedges thus formed on opposite sides of the dome, thrust against each other at the vertex, as in the case of an ordinary semicircular arch, and by this means keep each other in equilibrium. Of course no arch of this form if built alone could stand for a moment, as it would give way laterally; but in the dome this is prevented by the parts on each side of the rib under consideration.